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Uptake and accumulation of potentially toxic metals (Zn, Cu and Pb) in soils and plants of Durgapur industrial belt

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Abstract

Uptake and accumulation of metals in crops may cause possible health risks through food chain. A field survey was conducted to investigate the accumulation of potentially toxic metals contamination in soil and plants irrigated with complexed industrial effluents. Concentration of Zn, Cu and Pb was 205-255, 101-130, 118-177 $\mu g\ g^{-1}$ in rhizosphere soils and 116-223, 57-102 and 63-95 $\mu g\ g^{-1}$ d. wt. in root and 95-186, 44-75 and 27-58 $\mu g\ g^{-1}$ d. wt. in shoot, respectively. The trend in Cu and Pb was in the order: soil> root> shoot>seed while in Zn it was soil>root>seed>shoot. Roots accumulated a larger fraction of soil Cu (70%)> Zn (67%)> Pb (54%). Bioaccumulation coefficient of soil to root ranged from 51-98 for Zn, 54-85 for Cu and 43-63 for Pb. Analysis of variance showed marginal change in bioaccumulation coefficient, noticed between plants ($p>0.05$) while it varied significantly ($p<0.01$) between tissues and metals. It increased from root to seed/fruit (root > shoot > seed/fruit) while decreased between metals from Zn to Pb (Zn> Cu>Pb). Out of the three, two Cu and Pb accumulated to phytotoxic levels while Zn was within threshold limit of phytotoxicity.

Key words

Metal toxicity, Bioaccumulation coefficient, Industrial effluent, Durgapur industrial belt

Introduction

More than 100 industries including steel, cement, coal based thermal power plant, sponge iron, chemical, fertilizer, coal washeries as well as a cluster of medium and small scale ancillary industries of Durgapur industrial belt (DIB), India is discharging their wastewaters, enriched with heavy metals whose density >5 g cm^{-3} into the Tamala drain leading to heavy metals pollution of water-soil system and biota of the entire area. This contaminated waste has been used for cultivation of cereals, vegetables and others economically important crop plants by nearby farmers and are ignorant about the hidden toxicity of the heavily polluted discharges and their subsequent negative impacts.

Continuous discharge of sewage, sludge and industrial effluents into the agricultural lands is a matter of concern because of persistence of these metals in soils, uptake by crops and accumulative effects in animal and human beings. Soil to plant transfer is one of the key components of human exposure to metals through food chain (Cui *et al.*, 2004). Such metallic elements are not biodegradable and build up in soil system has been well reported (Li *et al.*, 2003; Boularbah *et al.*, 2006) and the subsequent uptake and distribution of these metals in plants (Herrero *et al.*, 2003; Greger and Lofstedt, 2004; Chao, 2006) and thereby increasing the risk of crop and food chain contamination (Sridhar Chary *et al.*, 2008).

The extent of these potentially toxic metals (PTM) and the impact thereof on human beings varies from one situation to another. It has become imperative to undertake comprehensive studies on evaluation of the heavy metal pollution of water, soil and plants in fast developing industrial belts of Durgapur and carry out impact assessment related to these.

During the recent past, DIB has drawn attention of researchers from different discipline and produced sufficient evidence of substantial contamination of Tamala drain water with toxic pollutants. Tamala drain wastewater is highly toxic to the standing crops and vegetables and cause retardation in growth and decrease of yield of rice up to 20%, pulses and oil seeds (Gupta *et al.*, 2008). Besides these, pollutants produced phytotoxic effect on rice, pulses and oil seeds (Athar *et al.*, 2002). It is well documented that plants grown on this polluted agricultural land are accumulating heavy metals through drain irrigation (Barman and Lal, 1994).

To our knowledge not much work has been done on the uptake and distribution of PTM on economically important plants irrigated continuously over the years with mixed industrial effluents. Hence, the present study was designed and aimed at to generate data on the uptake and bioaccumulation of the metals zinc (Zn), copper (Cu) and lead (Pb) on grains, vegetables, spices and weeds growing in Kalipur area. Also bioavailability and bioaccumulation coefficients had been worked out from the ratio of the PTM concentration in (i) plant roots related to pseudo total concentration in the rhizosphere soil, (ii) shoots related to roots and seed or fruits related to roots.

Materials and Methods

Sampling site: Kalipur village of Durgapur industrial belt (DIB) (Latitude, 23°32'23" N; Longitude, 87°19'55" E, 68.9 m above sea level) is greatly polluted either due to irrigation of land with mixed industrial effluents or the atmospheric surface deposition of aerosol emanating through chimneys. Durgapur industrial belt with a population of 12 lakh is spreads over the fertile agriculture land with an area of ~154 km^2 along the bank of the Damodar river in the Burdwan district of West Bengal, India (Fig. 1). The study reported here related to build up of toxic metals in soil and plants of Kalipur area irrigated with the Tamala drain, a polluted rivulet caused by the discharge of untreated or partially treated effluents from a host of

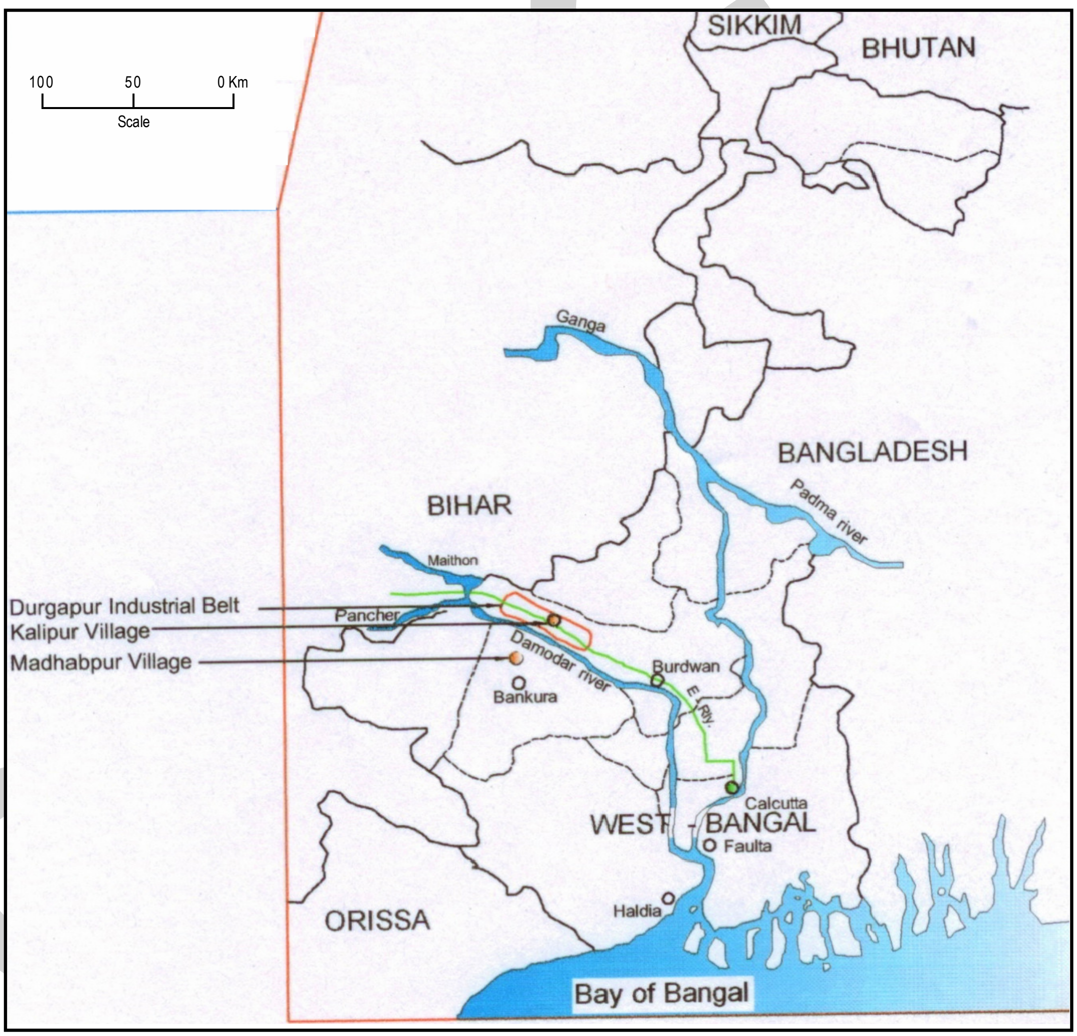

Fig. 1: Layout showing Durgapur industrial belt along the Damodar river, Kalipur area receiving Tamala Nala irrigation

>100 industries, that finds its way to the Damodar river at a distance of 15 km and is commonly used by farmers for irrigating their agricultural land because of lack of irrigation facility.

Collection and preparation of samples for analysis: Fourteen herbaceous plants species and same number of rhizosphere soil samples (0 to 30 cm) had been collected from the polluted area, Kalipur. For each plant sample, 5 plants of the same species were collected randomly keeping in mind the different samples of each plant species had the similar physiological age and identical morphology while soil samples were drawn from Kalipur area. These were 1 staple food crop, 2 oil seeds, 5 vegetables, 4 spices and 2 weeds. Cultivated crops were mostly suffering from wilting and disease.

The plant sample was washed first with running tap water to remove extraneous matter and then with distilled water. After washing the plant material was blotted dry, finally chopped and air dried. The dry plant material was pulverized, sieved through 2 mm sieve to ensure uniform particle size and stored in craft paper bags till needed for analysis. The specific plant parts segregated for analysis were roots, modified stem, stems, fruits/capsule/grains/ seeds. Prior to analysis, the samples were dried in an oven at 65°C till constant weight. One gram sample was digested with diacid digestion mixture (4v HNO_3: 1v $HClO_4$). The mixture was gently heated on an electrical hot plate till appearance of dense white fumes of $HClO_4$. If the digest was not clear, more digestion mixture was added and the digestion carried out further to incipient dryness stage. It was however not allowed to totally dry. At this stage 10-15 ml of distilled water was added, the contents were boiled, filtered through Whatman filter paper and made to volume (10 ml) with 0.01 N HNO_3. The clear digest was read for the PTM using Varian model Spectra AA-250 plus atomic absorption spectrophotometer (AAS). For quality assurance, replicate samples, blanks and standardized reference materials were used during analysis.

Statistical analysis: Average data uptake, transfer coefficient were submitted for statistical analysis. The uptake and mobilization of PTM in different plant tissues were assessed by bioaccumulation coefficient (BC). Data were analyzed using three factor analysis of variance (ANOVA), Pearson's correlation coefficient, simple linear regression and cluster analysis (CA). A two-tailed (α=2) probability value $p<0.05$ was considered to be statistically significant. All statistical analyses were performed using STATISTICA (Version 7), MS EXCEL (Microsoft office 97) and GrphPad Prism (Version 5).

Results and Discussion

PTM concentrations in soils and plants: The concentrations of Zn, Cu and Pb in the rhizosphere soils collected from the Kalipur area ranged from 205-255 (avg. 231.1 ± 4.0), 101-130 (avg. 114.9 ± 2.6), 118-177 (avg. 150.2 ± 5.6) $\mu g\ g^{-1}$, respectively and in root varied 116-223 (avg. 152.9 ± 8.8), 57-102 (avg. 81.2 ± 3.5) and 63-95 (avg 80.1 ± 2.7) $\mu g\ g^{-1}$ d. wt. (Table 1).

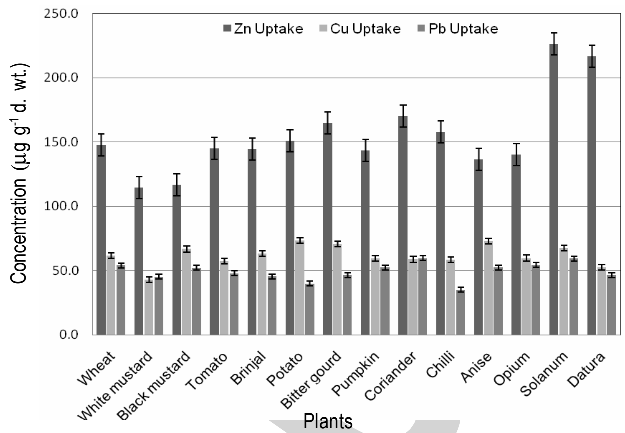

Fig. 2: Average uptake of Zn, Cu and Pb by individual plant species growing in Kalipur area

In the fruits of tomato, brinjal, bitter gourd, pumpkin, chilli and in the modified stem of potato and capsule of opium poppy; the metal concentrations ranged 155-175 (avg. 164.8 ±2.8) $\mu g\ g^{-1}$ d. wt for Zn, 43-56 (avg. 51.5 ±2.2) $\mu g\ g^{-1}$ d. wt. for Cu and 15-35 (avg. 27.2 ± 2.6) $\mu g\ g^{-1}$ d. wt. for Pb.

In wheat, white mustard, black mustard, coriander and anise in which Zn, Cu and Pb accumulation in seeds were also determined, the metal concentrations in seeds varied 125-184 (avg. 146.0 ± 10.2) $\mu g\ g^{-1}$ d. wt. for Zn, 24 -76 (avg. 46.4 ± 8.5) $\mu g\ g^{-1}$ d. wt. for Cu and 22-31 (avg. 26.2 ± 1.6) $\mu g\ g^{-1}$ d. wt. for Pb, respectively.

In coriander, relative to Zn concentration in roots and shoots, Zn concentration in seeds was particularly high 184 $\mu g\ g^{-1}$ d. wt. Seeds of black mustard accumulated much higher Cu than their roots or shoots. The Zn concentration followed the order soil > seed >root >shoot in cultivated crops and the Cu and Pb concentrations followed the order soil> root> shoot>seed in all plants.

Bioaccumulation of PTM in different plant parts: Root : Soil bioaccumulation of Zn varied from 51-98 (avg. 67± 4)%. Shoot : Root bioaccumulation of zinc was high (>100%) in case of wheat, tomato, coriander, chilli, opium poppy and anise. White mustard, black mustard and brinjal showed much higher bioaccumulation in fruits/seeds than in the vegetative parts of plants.

Root: Soil bioaccumulation of Cu varied from 54-85 (avg. 70±2)%. Shoot : Root bioaccumulation of Cu ranged from 45% in wheat to 88% in pumpkin. In wheat and opium poppy; shoot : root and seed : root bioaccumulation percentage was about the same but in white mustard, bitter gourd, anise and chilli, seed/fruit : root bioaccumulation was less than shoot : root bioaccumulation.

Soil bioaccumulation of Pb varied from 43 to 63 (avg. 54±2)%. There was little difference in the shoot : root bioaccumulation of Pb in different plants analysed for PTM bioaccumulation. It ranged from 42-61 (avg. 49±2)%. Compared to shoot : root bioaccumulation, seed / fruit : root bioaccumulation was low in each of the plant

Table - 1: Concentrations (µg g^{-1} d. wt.) of metals in soils and plant tissues and their basic statistics (Mean ± SE, n=14)

Plants	Zn				Cu				Pb			
	Soil	Root	Shoot	Seed / Fruit	Soil	Root	Shoot	Seed / Fruit	Soil	Root	Shoot	Seed / Fruit
Wheat	229	146	155	142	122	98	44	43	168	88	43	31
White mustard	219	116	95	133	105	57	47	24	134	76	37	22
Black mustard	239	121	104	125	109	74	50	76	170	91	41	24
Tomato	209	127	153	155	101	63	54	55	129	78	34	31
Brinjal	255	144	120	170	129	86	48	55	167	76	35	25
Potato	247	165	122	166	106	90	75	55	122	65	28	26
Bitter gourd	205	170	150	175	113	87	69	56	177	76	32	31
Pumpkin	225	158	114	158	105	72	63	43	154	82	40	35
Coriander	235	157	170	184	126	85	51	40	173	95	58	26
Chilli	242	146	162	165	110	76	54	45	118	63	27	15
Anise	246	128	136	146	130	102	67	49	173	82	47	28
Opium poppy	223	124	158	138	113	85	47	47	141	89	47	27
Solanum	241	223	186	270	126	93	59	50	146	91	46	41
Datura	221	216	176	258	114	69	50	38	131	69	40	30
Min.	205	116	95	125	101	57	44	24	118	63	27	15
Max.	255	223	186	270	130	102	75	76	177	95	58	41
Avg.	231.1	152.9	142.9	170.4	114.9	81.2	55.6	48.3	150.2	80.1	39.6	28
SE	4.0	8.8	7.5	11.5	2.6	3.5	2.5	3.1	5.6	2.7	2.2	1.6
SD	14.8	32.9	28.1	43.1	9.8	13.1	9.3	11.8	21.1	10.0	8.4	6.1

species. The root to shoot bioaccumulation of the Zn, Cu and Pb varied from 72-127, 45-88 and 42-61%, respectively. Based on average root to shoot bioaccumulation%, the 3 PTM could be arranged in the order, Zn (95) > Cu (70)> Pb (49).

The relationship of plant metal concentrations and rhizosphere soil revealed that the PTM concentration in plant roots was distinctly lower relative to the rhizosphere soil. Plant root accumulated a larger fraction (> 50%) of soil; Cu (70%)> Zn (67%)> Pb (54%). The soil to root bioaccumulation coefficient (%) ranged from 51-98 (average 67±4) for Zn, 54-85 (average 70±3) for Cu and 43-63 (average 54±2) for Pb.

Accumulation of different PTM in plants, related to their accumulation in the rhizosphere/ root, revealed difference in the mobility of the different elements from soil to plants. Relative to their concentration in the soil, plants absorbed larger proportion of Zn than Cu and Pb. Jung *et al.*, (2008) reported a wide differences in Cu, Cd, Pb, Zn accumulation by crop plants. Abdullahi *et al.*, (2007) found metal concentration in the tomatoes sample in the order of Pb> Cr> Cd.

According to Kiekens, (1995), the average Zn in soil 50 µg g^{-1} with a range 10-105 µg g^{-1}. The reference values used in the Netherlands for assessing soil contamination are 160 for Zn, 10 for Cu and 85 for Pb µg g^{-1} d. wt. (Netherlands Ministry of Housing, 1986 and 1991). The average Zn, Cu and Pb content in topsoil from England and Wales were 56.5, 29.6 and 12.3 µg g^{-1} dry soils (Mc Grath and Loveland, 1992). Kabata-Pendias and Pendias, (1992) reviewed the world wide literatures on Cu in uncontaminated surface soils and found the mean concentration ranging from 6-80 µg mg Cu g^{-1} d. wt.

Our results showed that Tamala Nala irrigation of the Kalipur area raised the soil level of Zn, Cu and Pb within the critical soil total concentration 14.23-121.85, 2.55-52.60, 5.46-35.00 µg g^{-1} d. wt. (Sharma *et al.*, 2007). However, the normal range in soils reported by Gupta *et al.*, (2008) is quite lower side 182-285, 22-166.5, 99.3-168.30 µg g^{-1} d. wt. for Zn, Cu and Pb, respectively. The concentration of Cu in the study area was lower than the level reported 2.5-133.3 (Tandi *et al.*, 2004), 7-145 (Mapanda *et al.*, 2005) and 2.55-203.45 µg g^{-1} d. wt. in Varanasi, India by Sharma *et al.*, (2007).

In the 5 plant species (wheat, white mustard, black mustard, coriander and anise) in which bioaccumulation coefficient of the PTM in seeds was studied, the average root to seed or fruit bioaccumulation coefficient (%) followed the order, Zn (109±4) > Cu (53±8) > Pb (30±2). In the fruits/modified stem/capsule of 7 plant species (tomato, brinjal, potato, bitter gourd, pumpkin, chilli and capsule of opium poppy), the average root to fruit bioaccumulation coefficient (%) followed the order, Zn (110±3) > Cu (63±4) > Pb (36±3). In the fruits of 2 weeds, *Solanum* and *Datura*, the average root to fruit bioaccumulation coefficient (%) followed the order, Zn (120±8.5) > Cu (55±39) > Pb (44±31). For Zn both root to shoot and shoot to seed / fruit bioaccumulation

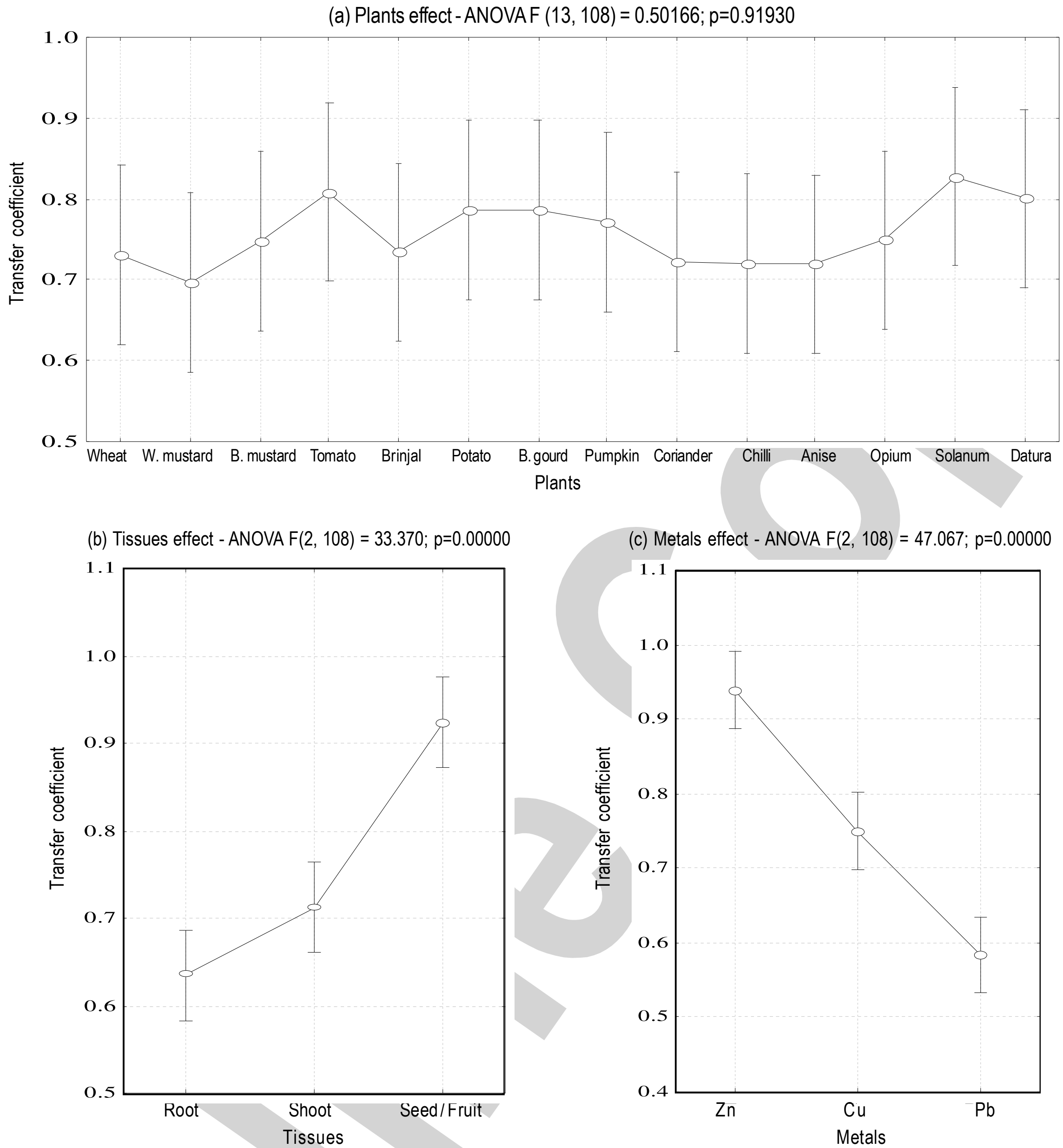

Fig. 3: Estimation of plants (a), tissues (b) and metals (c) effect on transfer coefficient by main effect ANOVA with 95% CI (vertical line)

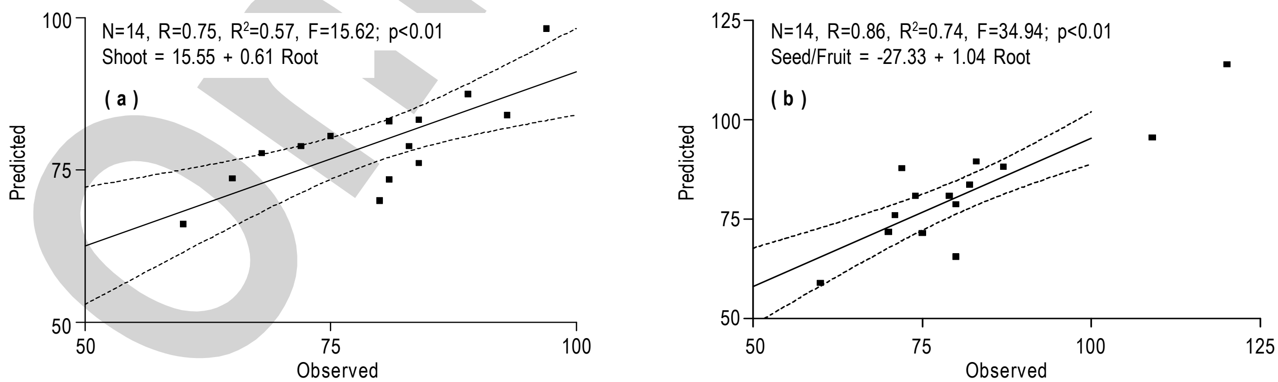

Fig. 4: Estimation of PTM ($\mu g\ g^{-1}$) in shoot (a) and seed/fruit (b) from root by regression analysis with 95% CI limits for β (regression coefficient)

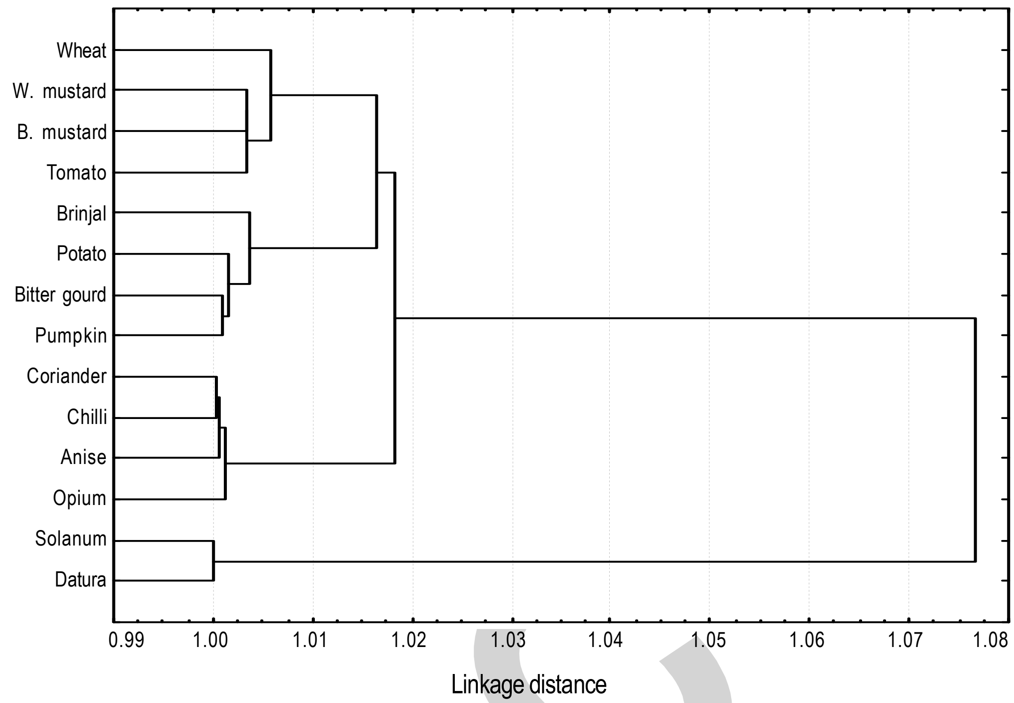

Fig. 5: Groupings of plants on the basis of transfer coefficient of metals in seed/fruit from shoot by cluster analysis

Table - 2: Transfer coefficient of metals in plants tissues and their basic statistics (Mean ± SE, n=14)

Plants	Zn				Cu				Pb			
	Soil to root	Root to shoot	Root to seed	Shoot to seed / Fruit	Soil to root	Root to shoot	Root to seed	Shoot to seed / Fruit	Soil to root	Root to shoot	Root to seed	Shoot to seed / Fruit
Wheat	0.64	1.06	0.97	0.92	0.80	0.45	0.44	0.98	0.52	0.49	0.35	0.72
White mustard	0.53	0.82	1.15	1.40	0.54	0.82	0.42	0.51	0.57	0.49	0.29	0.59
Black mustard	0.51	0.86	1.03	1.20	0.68	0.68	0.84	1.24	0.54	0.45	0.26	0.59
Tomato	0.61	1.20	1.22	1.01	0.62	0.86	0.87	1.02	0.60	0.44	0.40	0.91
Brinjal	0.56	0.83	1.18	1.42	0.67	0.56	0.52	0.94	0.46	0.46	0.33	0.71
Potato	0.67	0.74	1.01	1.36	0.85	0.83	0.61	0.73	0.53	0.43	0.40	0.93
Bitter gourd	0.83	0.88	1.03	1.17	0.77	0.79	0.64	0.81	0.43	0.42	0.41	0.97
Pumpkin	0.70	0.72	1.0	1.39	0.69	0.88	0.60	0.68	0.53	0.49	0.43	0.88
Coriander	0.67	1.08	1.17	1.08	0.67	0.60	0.47	0.78	0.55	0.61	0.27	0.45
Chilli	0.60	1.11	1.13	1.02	0.69	0.71	0.59	0.83	0.53	0.43	0.24	0.56
Anise	0.52	1.06	1.14	1.07	0.78	0.66	0.48	0.73	0.47	0.57	0.34	0.60
Opium poppy	0.56	1.27	1.11	0.87	0.75	0.55	0.55	1.00	0.63	0.53	0.30	0.57
Solanum	0.93	0.83	1.21	1.45	0.74	0.63	0.54	0.85	0.62	0.51	0.45	0.89
Datura	0.98	0.81	1.19	1.47	0.61	0.72	0.55	0.76	0.53	0.58	0.43	0.75
Min.	0.51	0.72	0.97	0.87	0.54	0.45	0.42	0.51	0.43	0.42	0.24	0.45
Max.	0.98	1.27	1.22	1.47	0.85	0.88	0.87	1.24	0.63	0.61	0.45	0.97
Avg.	0.67	0.95	1.11	1.20	0.70	0.70	0.58	0.85	0.54	0.49	0.35	0.72
SE	0.04	0.05	0.02	0.06	0.02	0.03	0.04	0.05	0.02	0.02	0.02	0.04
SD	0.15	0.18	0.09	0.21	0.08	0.13	0.13	0.18	0.06	0.06	0.07	0.17

was high. In case of Cu, root to seed/fruit bioaccumulation was higher than root to shoot bioaccumulation in black mustard and tomato, but it was not so in the other species. In fact, bioaccumulation of Zn in the fruiting part/seed was even higher than in the vegetative parts of the shoot.Sufficient or normal Zn concentration ranged between 25-150 $\mu g\ g^{-1}$ and excessive or toxic > 400 $\mu g\ g^{-1}$ in mature leaf tissues (Kabata-Pendias and Pendias, 1992). They provided 2 sets of critical concentration data range in plants (i) Zn (100-400), Cu (20-100) and Pb (30-300) $\mu g\ g^{-1}$ d. wt, above these concentration toxicity symptoms are likely to appear and (ii)

Table - 3: Correlation (n=14) of metals concentrations (µg g^{-1}) between soils and plant tissues

	Zn				Cu				Pb				Average PTM			
	Soil	Root	Shoot	Seed/ Fruit	Soil	Root	Shoot	Seed/ Fruit	Soil	Root	Shoot	Seed/ Fruit	Soil	Root	Shoot	Seed/ Fruit
Soil	1.00				1.00				1.00				1.00			
Root	0.02^{ns}	1.00			0.74**	1.00			0.63*	1.00			0.37^{ns}	1.00		
Shoot	-0.13^{ns}	0.62*	1.00		-0.11^{ns}	0.33^{ns}	1.00		0.52^{ns}	0.85**	1.00		0.12^{ns}	0.75**	1.00	
Seed/Fruit	0.04^{ns}	0.95**	0.68**	1.00	-0.06^{ns}	0.35^{ns}	0.45^{ns}	1.00	0.24^{ns}	0.43^{ns}	0.34^{ns}	1.00	0.04^{ns}	0.86**	0.70**	1.00

ns = not significant (p>0.05), * = significant (p<0.05), ** = significant (p<0.01)

beyond 100-900 µg Zn g^{-1} and 5-64 µg Cu g^{-1} d. wt may cause 10% depression in yield.

The weeds of the Kalipur area showed higher accumulation of heavy metal than that of the cultivated plants. In spite of this, the weeds demonstrated healthy morphology, showing greater tolerance to PTM pollution stress than the cultivated plants may be due to better current adaptation and rapid evolution. Today's tolerant species of weeds (previously sensitive and susceptible) possibly have evolved altered metabolic pathways of the cell to counter act the biochemical and physiological effects of the stress environment. Tap and lateral root system of the weed is stronger, healthier and quite normal than any tested crop plant which are comparatively less developed, unhealthy and shorter and lesser number of sub roots.

Grass and probably weed species possess highly specialized mechanisms to exude a class of organic acids termed siderophores (mugineic and avenic acids) capable of enhancing metal bioavailability in the rhizosphere and to enhance uptake into roots. According to Frost *et al.*, (2000) ability of translocation of metals is higher in younger plants than the older ones.

In this investigation, the mobility and uptake of Zn and Cu content from soil medium to root and root to shoot is significantly greater than the Pb content confirmed that Zn and Cu content occur primarily as soluble or exchangeable, readily bioavailable whereas much of Pb remains confined in the cell walls of the roots tissue as insoluble precipitates (phosphates, carbonates and hydroxyl-oxides) which are largely unavailable for plant uptake. This is in accordance with (Pitchel *et al.*, 2000) who reported a weak translocation of Pb within plants.

The differences in the extent to which different elements were accumulated by plants reflect differences in their uptake (from soil) and transport or mobility from roots to aerial parts. Interactions among the different PTM studied could account for differential accumulation of these elements in plants (Nan *et al.*, 2002). In the present study, it is not unlikely that accumulation of Zn and Cu in higher concentration could have prevented accumulation of Pb in plants in toxic concentrations. Luo and Rimmer, (1995) found that Cu-Zn interactions in a soil system were synergistic.

Marketable quality and quantity of food grain production per unit area can be decreased upto 10% due to substantial bioaccumulation of Zn, Cu and Pb without exhibiting any distinct symptoms such as chlorotic or necrotic spots on the leaves. The recommended value of daily dietary of Zn, 4.7-18.6 mg d^{-1} (Sandstead *et al.*, 1990) and 15 mg d^{-1} while for Cu 0.9-2.2 mg d^{-1} (Australian National Food Authority, 1992).

Bioaccumulation coefficients of all three metals show an increasing trend from root towards seed/fruit with few exceptions (Table 2). Analyzing the effects of plants, tissues and metals on bioaccumulation coefficients, main effect ANOVA show that the bioaccumulation coefficient was similar between plants (p>0.05) while differed significantly (p<0.01) between tissues and metals (Fig. 3).

The results show that the concentrations of Zn in tissues are independent (p>0.05 or p<0.01) of soils while the concentrations in shoot and seed/fruit depends (p<0.05) on root and seed/fruit on shoot also (p<0.01). The concentrations of Cu and Pb showed significant (p<0.01 or p<0.05) correlation between soil and root but their correlation among tissues varied differently. The concentrations of Cu did not correlate well (p>0.05) among tissues while Pb showed a significant (p<0.01) correlation between root and shoot. Average concentrations of PTE in soils and plants tissues showed similar correlation as of Zn but correlates with more significantly. Regression analysis (Fig. 4) showed that the average concentration of PTM in shoot and seed/fruit can be estimated significantly from root which accounts 57% (R^2=0.57) and 74% (R^2=0.74) variations of shoot and seed/fruit respectively.

Similarities (quantification/groupings) among plants were investigated on the basis of bioaccumulation coefficient value of seed/fruit using measure of single linkage and Euclidean distances (Cluster analysis) which agglomerated all 14 plants into 4 groups (clusters) except tomato (vegetable) which cluster with grains (Fig. 5).

The effects and bioavailability of heavy metals depends on factors such as environmental conditions, soil pH, chemical fertilizer, type of organic manure, genetic and cytological make up of individual plant species as well as its physiological conditions (Kisku et al., 2000). The study indicates that continuous use of Durgapur industrial belt effluents for irrigating the crops/weeds for longer period results in accumulation of heavy metals in soil. This may cause imbalances of nutrients in soil and plants and may also affect the animal/ human health adversely. Based on the ratio of accumulation of metals in fruits/ seeds white mustard, brinjal, coriander and chilli are preferable to cultivate than other studied crops in terms of health safety. No change in the phenotypic feature of weeds (no apparent sign of phytotoxicity) indicates that weeds have evolved its own mechanism of resistance against the adverse effect of heavy metals. Further, study suggests that these naturally growing heavy metal tolerant weeds can be used for phytoremediation of multiple-metal-contaminated soil.

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References

Abdullahi, M.S., A. Uzairu, G.F.S. Harrison and M.L. Balarabe: Trace metals screening of tomatoes and onions from irrigated farmlands on the bank of river Challawa, Kano, Nigeria. *J. Enviro. Agric. Food Che.*, **6**, 1869-1878 (2007).

Athar, R. and M. Ahmad: Heavy metal toxicology : Effect on plant growth and metal uptake by wheat, and on free living *Azotobacter., Water, Air Soil Pollution,* **138**, 165-180 (2002).

ANFA: The 1992 Australian market basket survey Canberra. Australian Government Publishing Service, **99** (1992).

Barman, S.C. and M.M. Lal: Accumulation of heavy metals (Zn, Cu, Cd and Pb) in soils and cultivated vegetables and weeds grown in industrially polluted fields. *J. Environ. Biol.*, **15**, 107-115 (1994).

Boularbah, S., C.B. Christophe, G.M. Gabriel and J.L. Jean-Louis: Heavy metal contamination from mining sites in South Morocco, 1. Use of a biotest to assess metal toxicity of tailings and soils. *Chemosphere*, **63**, 802-810 (2006).

Chao L., Q. Zhou, S. Chen and S. Cui: Speciation distribution of lead and zinc in soil profiles of the Shenyang smelter in Northeast China. *Bull. Environ. Contam. Toxicol.*, **77**, 874-881 (2006).

Cui, Y.J., Y.G. Zhu, R.H. Zhai, D.Y. Chen, Y.Z. Huang, Y. Qiu and J.J.Z. Liang: Transfer of metals from soil to vegetable in an area near a smelter in Nanning China. *Environ. Int.*, **30**, 785-791(2004).

Frost, H.L. and L.H. Ketchum Jr.: Trace metal concentration in durum wheat from application of sewage sludge and commercial fertilizer. *Ad. Environ. Res.,* **4**, 347-355 (2000).

Greger, M. and M. Lofstedt: Comparison of uptake and distribution of cadmium in different cultivars of bread and durum wheat. *Crop Sci.*, **44**, 501-507 (2004).

Gupta, S., S. Nayek, R.N. Saha and S. Satpati: Assessment of heavy metal accumulation in macrophyte, agricultural soil and crop plant adjacent to discharge zone of sponge iron factory. *Environ. Geol.*, DOI 10.1007/S00254-007-1025Y (2008).

Herrero, E.M., A. Lopez-Gonzalvez, M.A. Ruiz, J.A. Lucas-Garcia and C. Barbas: Uptake and distribution of zinc, cadmium, lead and copper in *Brassica napus* var.oleifera and *Helianthus annus* grown in contaminated soils. *Int. J. Phytorem.*, **5**, 153-167 (2003).

Jung, M.C.: Heavy metal concentration in soil and factor affecting metal uptake by plants in the Vicinity of a Korean Cu-W mine. *Sensors*, **8**, 2413-2423 (2008).

Kabata-Pendias, A. and H. Pendias: Trace elements in soils and plants. 2nd Edn., CRC Press, Boca Raton, Fla, USA (1992).

Kiekens, I. : Zinc. *In*: Heavy metals in soils. 2nd ed., B.J. Alloway Blackie Academic and Professional, London. pp. 284-285 (1995).

Kisku, G.C., S.C. Barman and S.K. Bhargava: Contamination of soil and plants with potentially toxic elements irrigated with mixed industrial effluent and its impact on environment. *Water Air Soil Pollut.*, **120**, 121-127 (2000).

Li, Y.M., R.L. Chaney, E.P. Brewer, J.S. Angle and J. Nelkin: Phytoremediation of nickel and cobalt by hyperaccumulator *Alyssum* species grown on nickel-contaminated soils. *Environ. Sci. Technol.,* **37**, 1463-1468 (2003).

Luo Y. and D.L. Rimmer: Zn-Cu interaction affecting plant growth on a metal contaminated soil. *Environ. Pollut.*, **88**, 79-83 (1995).

Mapanda, F., E.N. Mangwayana, J. Nyamangara and K.E. Giller: The effect of long term irrigation using wastewater on heavy metal contents of soils under vegetables in Harare, Zimbabwe. *Agric. Ecosyst. Environ.*, **107,** 151-161 (2005).

Mc Grath, S.P. and P.J. Loveland: The soil geochemical atlas of England and Wales, Blackie Academic and Professional, Glassgow (1992).

Nan, Z., J. Li, J. Zhang and G. Cheng: Cadmium and zinc interactions and their transfer in soil-crop system under actual field conditions. *Sci. Total Environ.*, **285**, 187-195 (2002).

Netherlands Ministry of Housing, Physical Planning and Environment, Environmental Quality Standards for Soil and Water, Netherlands Ministry of Housing, Physical Planning and Environment, Leidschendam, Netherlands, 1986 and 1991.

Pitchel, J.K., K. Kuroiwa and H.T. Sawyer: Distribution of Pb, Cd and Ba in soils and plants of two contaminated soils. *Environ. Pollut.*, **110**, 171-178 (2000).

Sandstead, H.H., F.R. Dintzis, T. Bogyo, D. Milne and L.M. Klevay: Dietary factors that can impair Ca and Zn nutritive of the elderly. In: (Eds.: J. Priceley and H.H. Sandstead). Nutrition and aging. New York, Alam R. Liss. PP. 241-262 (1990).

Sharma, R.K., M. Agarwal and F. Marshall: Heavy metal contamination of soil and vegetables in suburban areas of Varanasi, India. *Ecotoxicol. Environ. Saf.,* **66**, 258-266 (2007).

Sridhar Chary, N., C.T. Kamala and D.S. Suman Raj: Assessing risk of heavy metals from consuming food grown on sewage irrigated soils and food chain transfer. *Ecotoxicol. Environ. Saf.*, **69**, 513-524 (2008).

Tandi, N.K., J. Nyamangara and C. Bangira: Environmental and potential health effects of growing leafy vegetables on soil irrigated using sewage sludge and effluent : A case of Zn and Cu. *J. Environ. Sci. Hlth. B,* **39**, 461-471 (2004).